Comprehensive Evaluation Model of Garage Design Based on Analytic Hierarchy Process

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Abstract. With the emergence of parking problems, the design and development of garages is increasingly important. This paper studies the comprehensive evaluation of design schemes in garage design steps and establishes a comprehensive evaluation model of garage design scheme based on analytic hierarchy process. The mathematical model mainly includes the steps of constructing the evaluation hierarchy, constructing the judgment matrix, checking the consistency, calculating the weight and final score. Finally, we use the evaluation model to evaluate the three garage design schemes in Figure 2. The final evaluation results are consistent with the results obtained through user surveys, which proves that the evaluation model is reasonable and reliable.

Keywords: Garage Design, Evaluation Model, Analytic Hierarchy Process.

1. Introduction

With the rapid development of the economy and the continuous improvement of people's living standards, cars have gradually entered the ordinary people's homes as a common means of transportation. The problem of parking difficulties that followed has become more and more obvious, and the problems in first-tier cities such as Beijing and Shanghai in China are more serious [1]. Appeared in the 1920s, the mechanical stereo garage, which was first developed by American scholars, is an effective parking device for improving urban static traffic. It has the advantages of small footprint, relatively low cost, removable disassembly, safety and reliability, and has become an effective means to solve the parking problem [2]. Therefore, the design and development of new garages are of great significance for the construction and planning of modern smart cities. This paper mainly studies the design evaluation of the garage design steps, and combines the Analytic Hierarchy Process [3] to propose a comprehensive evaluation system for garage design.

2. Principle of Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is a multi-objective evaluation method that combines qualitative and quantitative analysis proposed by American operations researcher Saaty in the 1970s. The basic idea of the method is to decompose the problem into different constituent factors according to the nature of the problem and the goal to be achieved. According to the interrelated influences and affiliation of factors, these factors are integrated into different levels to form a multi-level analytical structure model. The problem is ultimately attributed to the determination of the relative importance of the lowest level factor relative to the highest-level factor (total target) or the relative merits.

When using the analytic hierarchy process for design evaluation, we decompose the decision problems into different hierarchies in the order of the overall goal, sub-goals, evaluation criteria, and specific preparation plans. Then, by means of solving the matrix eigenvectors, we can find the priority of each element of each level to the previous level. Finally, the final evaluation score of the plan to be evaluated for the overall target is obtained, and the plan with the highest score is optimal.

3. Garage Design Evaluation Model

3.1 Evaluation Hierarchy of Garage Design

We establish a hierarchy of program evaluations based on various evaluation criteria and specific indicators for the program to be evaluated. The model is mainly divided into the final target layer, the

evaluation criteria layer, the specific indicator layer and the solution layer. The hierarchical structure of the garage design scheme evaluation established in this paper is shown in Fig.1.
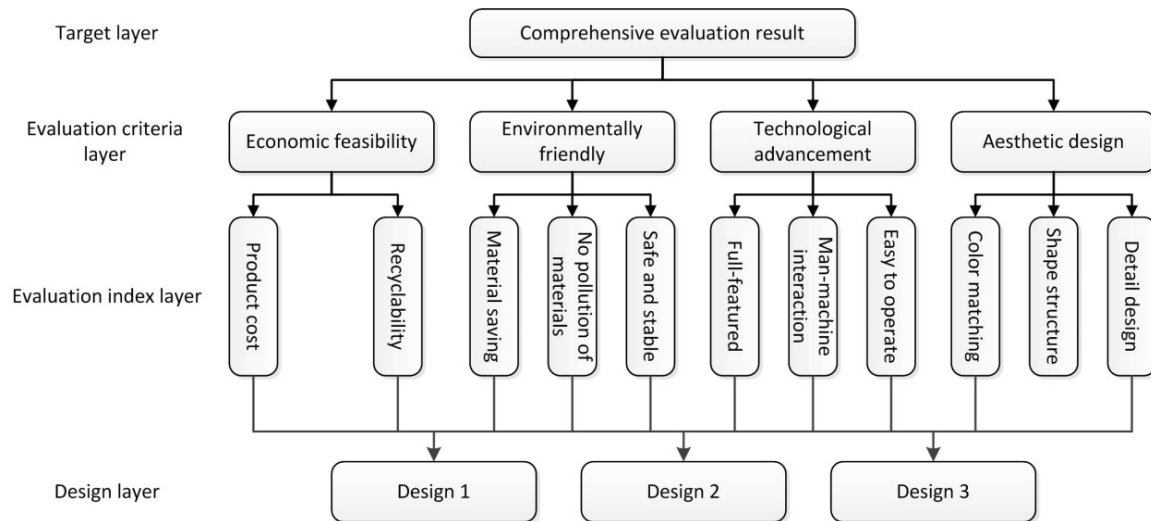

Figure 1. Hierarchy structure of garage design evaluation model

3.2 Comparison Matrix

The factors $c_1, c_2, \cdots, c_n$ in the indicator layer tend to have different effects on their superior (criteria layer) factors. For any two factors c_i and c_j, the ratio scale a_{ij} is used to indicate the ratio of the influence of c_i and c_j on their superior factors, and constitutes a judgment matrix denoted as $A = (a_{ij})_{n \times n}$. It can be seen from Fig. 1 that the value of n is 11. There are four criteria in the criteria layer of the garage evaluation model in this paper. Therefore, four judgment matrices should be constructed and recorded as A_1, A_2, A_3, A_4. These matrices satisfy the following properties: $a_{ii} = 1, a_{ij} = 1/a_{ji}$. Similarly, we can construct the judgment matrix on the upper layer according to the degree of influence of the criterion layer factor on the final target layer recorded as $B = (b_{ij})_{m \times m}$, and Fig.1 shows that m is equal to 4. The value of the ratio scale a_{ij} is determined by the experts by means of pairwise comparison. The range of values and the actual meaning are shown in Table 1.

Table 1. The value range and actual meaning of the ratio scale

a_{ij}	The actual meaning
1	c_i and c_j have the same influence
3	c_i's influence is slightly stronger than c_j
5	c_i's influence is stronger than c_j
7	c_i's influence is significantly stronger than c_j
9	c_i's influence must be much stronger than c_j.
2,4,6,8	The ratio of the influence is between the above two adjacent levels
1/2,...,1/9	$a_{ij} = 1/a_{ji}$

3.3 The Importance Weight of Each Factor

In the previous section, we obtained the relative importance of the factors in the same layer by means of a pairwise comparison. Next, we need to find the absolute importance of these factors relative to the upper factors, that is, the weight of influence. This paper uses the eigenvalue method to obtain the weight of each factor. The vector of each column (or each row) of the judgment matrix A is geometrically averaged and normalized. The obtained result can be approximated as a weight, and the calculation formula is as follows:

$$\omega_i = (\prod_{j=1}^{n} a_{ij})^{\frac{1}{n}} \Big/ \sum_{k=1}^{n} (\prod_{j=1}^{n} a_{kj})^{\frac{1}{n}} , n = 11 \tag{1}$$

Then the maximum eigenvalue of the matrix judgment matrix A is λ_{max}, and the corresponding normalized eigenvector is $W = \{\omega_1, \omega_2, \cdots, \omega_n\}$. In the garage evaluation model of this paper, there are 4 judgment matrices from the index layer to the criterion layer, so there are 4 weight vectors:

$$\begin{aligned} W_1 &= \{\omega_{11}, \omega_{21}, \cdots, \omega_{n1}\} \\ W_2 &= \{\omega_{12}, \omega_{22}, \cdots, \omega_{n2}\} \\ W_3 &= \{\omega_{13}, \omega_{23}, \cdots, \omega_{n3}\} \\ W_4 &= \{\omega_{14}, \omega_{24}, \cdots, \omega_{n4}\} \end{aligned} \tag{2}$$

Using the same method, you can get the weight vector of the judgment matrix B which is recorded as:

$$W_0 = \{\beta_1, \beta_2, \cdots, \beta_m\} \tag{3}$$

3.4 Comprehensive Evaluation Result

If all the judgment matrices obtained above pass the consistency test, the direct weights of the factors in the index layer relative to the final target layer can be determined according to the weight vector obtained in the text. The method is as follows:

$$\gamma_i = \sum_{j=1}^{m} \omega_{ij} \beta_j \tag{4}$$

Then the weight vector of each evaluation index relative to the final decision is:

$$R = \{\gamma_1, \gamma_2, \cdots \gamma_n\} \tag{5}$$

Next, we score the n indicators of a design and record the score vector as:

$$s = \{s_1, s_2, \cdots s_n\} \tag{6}$$

The total evaluation score for this program is:

$$S = \sum_{i=1}^{n} s_i \gamma_i \tag{7}$$

We can use this model to calculate the final score S of each garage design, and the design with the highest score is the best.

4. Practical Application of the Model

Fig.2 shows three car garage designs. Next, we use the above evaluation model to conduct a comprehensive evaluation of these three programs.

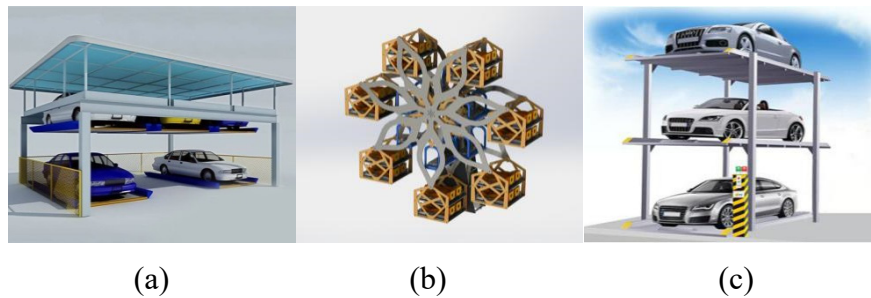(a)   (b)   (c)

Figure 2. Three car garage designs

Several mechanical design experts were invited to participate in the evaluation. With the help of experts, we successfully constructed five judgment matrices that can pass the consistency test [3], and then calculated the weight vector of each evaluation index relative to the final decision. This weight vector is expressed as follows:

$$R = \begin{Bmatrix} 0.2612, 0.1384, 0.2229, 0.2306, 0.2690, 0.2384, \\ 0.1845, 0.2768, 0.2690, 0.2229, 0.2229 \end{Bmatrix}$$

The indicators for each of the three designs options are as follows:

Table 2. Score of each indicator of the three programs

Evaluation index	Score of design a	Score of design b	Score of design c
Product cost	3	7	5
Recyclability	7	3	1
No pollution	7	5	3
Material saving	3	5	5
Safe and stable	5	5	3
Full-featured	7	3	9
Easy to operate	5	3	7
Man-machine interaction	5	5	7
Color matching	7	3	3
Shape structure	7	4	5
Detail design	6	3	5

According to Equation 7, the final scores of the three designs can be calculated as:

$$S_a = \sum_{i=1}^{11} s_{ai}\gamma_i = 0.43$$

$$S_b = \sum_{i=1}^{11} s_{bi}\gamma_i = 0.26$$

$$S_c = \sum_{i=1}^{11} s_{ci}\gamma_i = 0.31$$

According to the score, the design a is the best, and the design b is the worst. This result coincides with the conclusions we have reached through user research. Therefore, we can say that this evaluation model is reliable.

References

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